



Control system design and commissioning of photovoltaic trough concentrator systems installed at the Murdoch University South st campus

ENG460 Engineering Thesis

*A report submitted to the School of Engineering and
Energy, Murdoch University in partial fulfilment of the
requirements for the degree of Bachelor of Engineering*

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Abstract

This thesis is concerned with the upgrades to the Photovoltaic Trough array now installed at the Murdoch campus. The array was originally installed in Rockingham as a single 80 panel array. The project was taken over by the engineering department to restore its functionality as a teaching resource. As part of the relocation the array of panels was split into 3 smaller systems. A Large array with 40 panels and 2 smaller arrays with 8 panels each. The key components of this project were to design, implement and test control systems on the 3 arrays.

The project consisted of two basic streams of work. The Large array being the first stream which required more implementation and testing to revive the existing control system by using the old controller with new wiring and some minor upgrades to the way it operates. The second stream involved the designing of a new control system for the two identical smaller systems from the ground up. This required a bit of problem solving adapting left over structural components to work with VSD's directly mounted to the axis of the system. The two streams ran in parallel with downtime in one utilised in the other.

The large array control system at the end of this project is now tracking the sun again. This stream of the process is now complete with the array ready to be connected to inverters to convert their generated power into useable power by the electricity grid. This stream of the project was prioritised over the smaller arrays stream as other projects are reliant on the completion of this part such as the connection of the inverters.

The small array stream has been extensively designed and is nearly ready to move onto the implementation phase. Due to the time constraints of the technical staff at the University, manufacturing will be delayed until the completion of the new engineering building. Documentation of the work undertaken will help any future projects complete the small system for use as a teaching resource.

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Glossary

Azimuth	The angle of the Sun with respect to North on the horizontal plane. Used in the calculation of roll angle.
Coordinated Universal Time (UTC)	UTC is the basis of most legal time systems. It is kept within 0.9 seconds of UT1 by introducing leap seconds. (Ibrahim & Afshin, 2008)
Declination	Declination is used as one of two coordinates for pointing to a celestial body (Sun) using the equatorial coordinate system. Declination in astronomy is comparable to geographic latitude and is measured in degrees north or south of the equator.(Wikipedia, 2010)
ENG454	Industrial Computer Systems Design Unit. Students are involved in the design, specification and implementation of a control system.
Ephemeris	A time where a celestial body will be in a certain position.
Geocentric	The Suns position with respect to the Earth
Gregorian calendar	The Gregorian calendar is the internationally accepted civil calendar. The Gregorian calendar was introduced in 1582 which reformed the Julian calendar due to an error in the calendar assuming the time between vernal equinoxes is 365.25 days.
Heliocentric	The Earth's position with respect to the Sun.
IPOS	A SEW Eurodrive proprietary system which deals with the position and sequencing of a VSD which allows for simplified programming of a higher level controller.(SEW Eurodrive, 2009)

Julian Day	A Julian day is a day on the Julian calendar. A previously used Romanian based calendar which was replaced by the Gregorian calendar in 1582
Local Time (LT)	The local time of a place on the Earth's surface. Local time is offset from (UTC) by the time zone of the place. Local time can be subject to Daylight savings at certain times of the year.
Nutation	Nutation is a rocking, swaying or nodding motion in the axis of rotation of a planet such as the Earth
Obliquity	The obliquity of the ecliptic is the angle of inclination of the Earth's equator with respect to the plane of its orbit. Obliquity produces the apparent relative tilt of the Earth's polar axis which causes the annual seasons(Wikipedia, 2010).
Photo-voltaic (PV)	PV is a method of converting sunlight directly into electrical energy.
Right ascension	Right ascension is used as one of two coordinates for pointing to a celestial body (Sun) using the equatorial coordinate system. Right ascension is comparable to geographic longitude.(Wikipedia, 2010)
Roll	The angle the sun is relative to north in an easterly direction
SBus	An industrial communication method involving a 2 wire communication bus.
Sidereal time	Sidereal time is measured by the rotation of the Earth, with respect to the stars (rather than relative to the sun). 1 sidereal day is approximately 23 h 56 min (Giesen, 2007)

Stow	A position the array moves to for storage. This position is often where the array is protected from damage.
SWIS	The South West Interconnected System is the West Australian electricity supply network which spans the metropolitan area and some country areas of Western Australia.
Tilt	The angle the sun is away from the zenith in a north or south direction. (See Figure 4)
Topocentric	The position of the sun with respect to the observers geographical location
Universal Time (UT)	Universal time or Greenwich civil time is based on the earth's rotation and counted from 0-hour at midnight. UT is the time used to calculate the solar position in the algorithm. UT is sometimes referred to as UT1. (Ibrahim & Afshin, 2008)
VSD	A variable speed drive is a motor capable of moving at variable speeds with the use of an inverter.
Zenith	The direction pointing directly above a particular location.

Introduction

The original implementation of the Photovoltaic trough (PVT) arrays has been plagued by technical issues since its installation as an 80 mirror array in Rockingham. A picture of the original installation in Rockingham is shown in Figure 1. The array was moved up to the Murdoch campus as the engineering services were progressively being moved to the campus with the relocation of the department. This installation was originally handled by contractors who abandoned work on the project without finishing. The movement and reconfiguration of the array up to the Murdoch campus was a chance to fix these issues as well as improve the system so it can be a valuable asset for the School of Engineering and Energy.

Today there are many different renewable energy technologies available and extensive research is being undertaken worldwide into the development of new technologies in the pursuit of finding environmentally friendly alternatives to burning fossil fuels. Currently many renewable technologies have a high initial capital cost as the technology is still developing. However concentrated photovoltaic installations have an advantage over conventional solar panels as they utilise cheap concave mirrors to concentrate sunlight onto PV cells. A tracking system is used to keep the mirrors aligned so the sunlight is concentrated onto the receivers.

This project can be split into two major components. The recommissioning of the large array control system is the first component. This involves the design, implementation and testing of upgrades to the large array control system to enable it to resume tracking the sun again. Once completed the School of Engineering and Energy can proceed with the installation of inverters and connection to the power grid for the generation of power.

The second major component is the design and implementation of a control system for the two smaller arrays. The small arrays have begun development of a control system from scratch as they were made of structural components left over from the Rockingham installation. The new control system consists of variable speed drives which directly drive the array. The control system showcases newer technologies to students such as VSD's, Labview and RS-485 technologies.

With future work the systems will serve as a teaching resource both for Renewable energy students and for Industrial computer systems students to develop and maintain these systems for the purposes of testing and developing renewable technologies.



Figure 1: Original 80 mirror installation at Rockingham

1.0 Photovoltaic Trough Theory

Renewable energy systems are seen as the future of energy generation. It is hoped that developments in renewable energy technologies will help them compete with cheaper unsustainable fossil fuels for the preferred choice of energy generation. At the moment renewable energy accounts for only a small percentage of energy generation as the technology is expensive per kW of generation compared to a fossil fuel burning power plant.

Renewable energy is also intermittent as it relies on harnessing a particular energy. For example photovoltaic arrays rely on the sun shining to convert its energy into useable electricity. However the sun only shines during the day and can be shielded by clouds which reduces the array power output.

1.1 Concentration of Sunlight

The concentrator system used at Murdoch comprises of parabolic mirrors that concentrate the incoming direct sunlight onto the solar cells that are positioned facing the mirrors at the focal point of the light being reflected (Smeltlink). Figure 2 illustrates the sunlight which is being reflected into the solar cells.

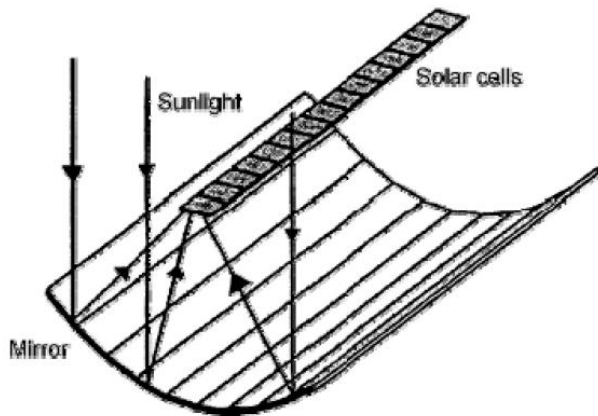


Figure 2: Concentration of Sunlight (Smeltlink)

The parabolic mirrors concentrate the sunlight to 20 to 30 suns. The term “suns” is simply a multiple of the suns light intensity where one (Edwards, 2010). The efficiency of the solar cells is improved by concentrating the sunlight. The purchase price of concentrated photovoltaic’s (CPV) is thus reduced as there are fewer solar cells needed to produce the same amount of power.

The minimum efficiency for each cell is 20% but the average cell efficiency is close to 22% at 20-30 suns (Edwards, 2010).

Compared to conventional flat panel solar cells, CPV is advantageous because the solar collector is less expensive than an equivalent area of solar cells. CPV hardware (solar collector and tracker) is targeted to be priced well under 3 USD/Watt, whereas silicon flat panels that are commonly sold are 3 to 5 USD/Watt (not including any associated power systems or installation charges)(Wikipedia, 2010)

The heat generated by concentrated sunlight needs to be taken into consideration. At the focal point of light temperatures can reach roughly 350°C (Wikipedia, 2010). This heat is dissipated by passive heat sinks attached above the solar cells. It is critical that cell junction temperature is kept cool to maintain efficient levels of power conversion (Wikipedia, 2010). Figure 3 shows the passive heat sinks used to dissipate the heat generated by the concentrated sunlight on the solar cells.

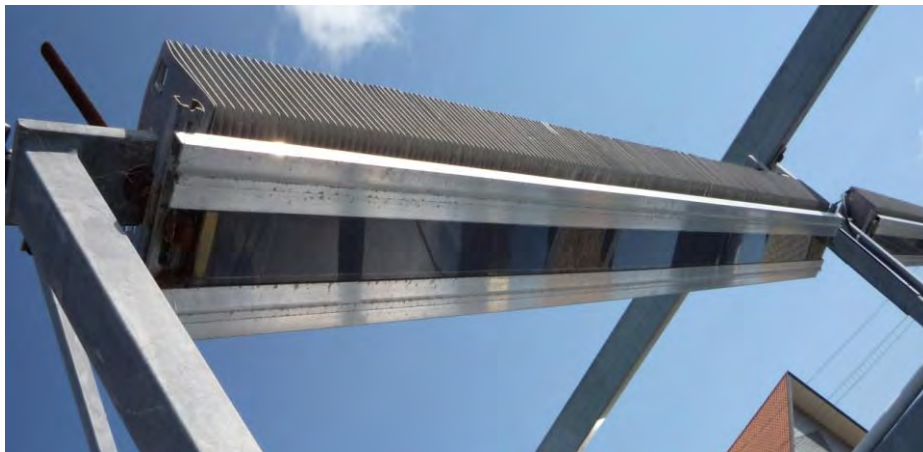


Figure 3: Solar cell with heat sinks (Edwards, 2010)

1.2 Types of Controllers

For the solar cells to operate effectively the sun must be directly reflected back to the cells. To do this a tracking system is employed to move the array to the correct point that reflects the sunlight back to the cells. There are various types of trackers that can perform this task.

Active Tracker

An active tracker uses photo sensing diodes that are configured in a differential circuit so they output null when receiving the same light flux. The active tracker relies on locking onto the sun using feedback photo sensing diodes and then following the movement of the sun. These trackers can be complicated in their setup as they are influenced by clouds and

weather conditions and other light distortions. If there is not enough light, the light sensors may not energise the differential circuit and the lock on the sun will be lost.

Sun sensors that detect the hot spot of the Sun will also often detect the bright edges of moving clouds (lensing effect), following them intermittently then moving back to the Sun, and can even lock on to strong reflections such as those pesky ones that bounce off of a parked-car windshield or, more often, the shiny surface of another tracker. Such distractions which are indistinguishable from the actual Sun by most electronic sensor circuitry, can cause an almost constant motion of the motors while hunting for the hottest part of the sky and actually use high levels of power (full motor current) all day long where the normal assumption is that the array only moves (updates position) once in a while and then only briefly. (Leonard, Solartrak Software interface manual, 2002)

Passive Tracker

A passive tracker uses a low boiling point compressed gas fluid that is driven to one side or the other (by solar heat creating gas pressure) to cause the tracker to move in response to an imbalance (Wikipedia, 2010). This method of tracking is a non precise control method and is not suitable for some types of concentrating photovoltaic arrays. It however would improve the efficiency of common PV panels.

The design of a passive tracker is crude and needs other components to improve operation: (Wikipedia, 2010)

- Viscous dampers to prevent motion in response to wind gusts
- Shader/Reflectors to reflect early morning sunlight to tilt the panel towards the sun in the morning which can take up to an hour
- Self releasing tie down that positions the panel slightly past the zenith.
- Tie downs used in the evenings to stow the array

Chronological Tracker

Chronological tracking is a simple open loop tracking method. It performs calculations which takes geographical location and time as its main inputs to calculate the zenith and azimuth angles with respect to a reference point. Properties of the system are taken into account such as the ratio of counts to degrees of movement and an offset to the Zenith and North point from reference points. A diagram of these angles is shown in Figure 4. The tracking algorithm compensates for the movement of the earth by turning at an equal rate as the

earth, but in an opposite direction (Wikipedia, 2010). These trackers have the potential to be very accurate if setup correctly.

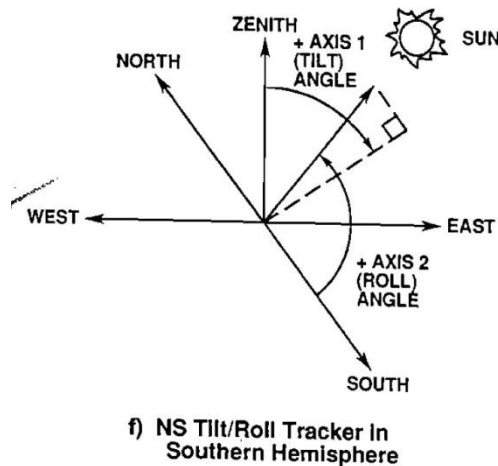


Figure 4: Angles associated with tracking the sun (Leonard, Development Unit User Manual, 2002)

Although this method would seem to waste energy, since the unit will track on cloudy days when there is little available energy it does not suffer from interruption from reflections like active trackers. (Leonard, Solartrak Software interface manual, 2002)

The current sun position is continuously recomputed. When a comparison of the actual mechanical position is different from the computed sun position the controller causes the mechanism to move until the two are once again the same. The 'Tracking Band' is the envelope of the array focal-line path resulting from the zigzag motion implicit in a periodic position update. 'Tracking' is accomplished by waiting until the focal-line drifts (due to relative motion of the Sun) out of the dead band then moving the array past the Sun, then waiting some more and updating the position again. (Leonard, Solartrak Software interface manual, 2002) The tracking band is illustrated in Figure 5.

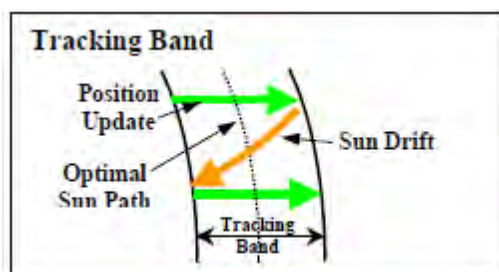


Figure 5: Tracking band (Leonard, Solartrak Software interface manual, 2002)

When the array position drifts outside the dead band window, the controller turns on the motor until the position is 'coast counts' away from the Request Position. The Coast Counts

parameter allows for system momentum to carry the array further than the motor turn-off point without drastically overshooting the Request Position. (Leonard, Solartrak Software interface manual, 2002)

2.0 Large Array

The large array is a scaled version of the 80 panel array that was installed in Rockingham. The new 40 panel array uses the existing 6811 microcontroller based control system that was used at Rockingham. The large array uses the existing actuation systems which were installed at the Rockingham campus manufactured by Precision Solar Technologies. A diagram of the construction of the arrays is shown in Figure 1.

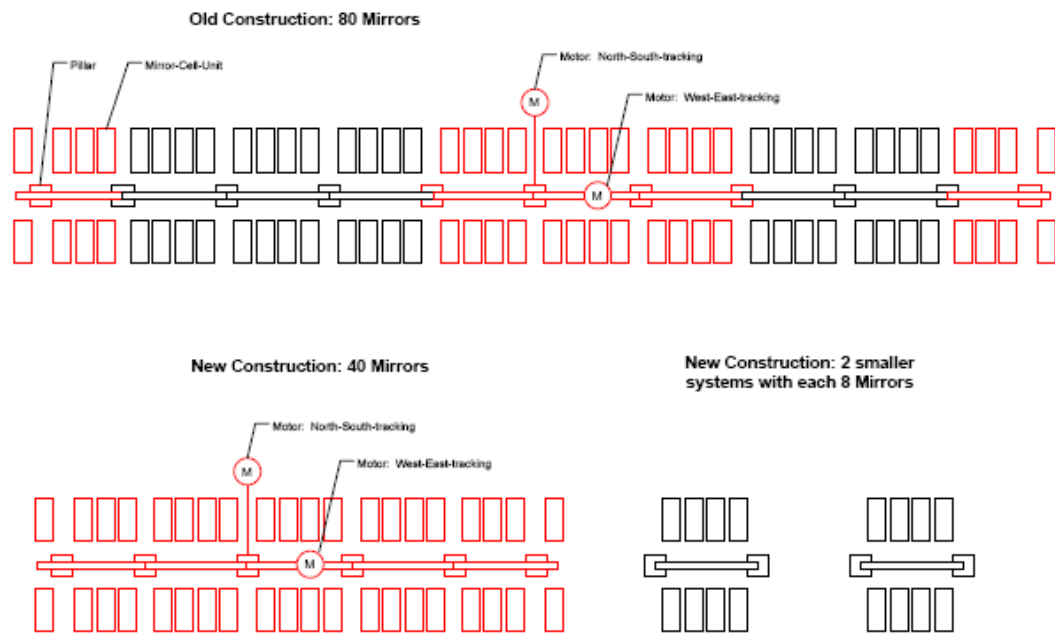


Figure 6: Construction of Arrays at Murdoch Campus (Kretschmer, 2009)

Work has been done to coordinate the re-commissioning of this system. At the start of the project Thistle Contracting had finished work fixing mechanical issues with the array. The system was able to be moved by manual control from a temporary switching system that is directly connected to the motor. A picture of this temporary switch is shown in Figure 7. The switch allowed the movement of the array for testing purposes however care had to be taken to not damage the array as the limit switches were not connected.



Figure 7: Temporary Motor Switch

Work needed to be done to re-commission the controller and actuation system so that the controller could be placed into tracking mode again. This included:

- Re-wiring the control system
- Installing a new field box
- Improving reliability of the system by using interlocking relays
- Tuning the controller by adjusting limit switches so it can track again
- Testing the control system

Once the control system is tested the School of Engineering and Energy can proceed with the installation of the inverters and wiring of the generation side of the arrays.

2.1 Solar Trak Controller Board

The intention for the large array after splitting was to use the existing controller which would save reconfiguring the system for use with another controller. The Solar Trak Controller uses mathematical computation for the sun's position in the sky and counts electronic pulses (feedback) to determine the actual array (moving part of the solar tracker) position. By making these two positions coincide on a continuous basis throughout the day it will cause the array to follow the sun. (Leonard, Solartrak Software interface manual, 2002)

The controller computes the local celestial bearing of the sun with respect to the earth by applying a published set of equations to characterize the motion of the Earth with respect to the sun to within 0.01 degrees using the following inputs:

- Local Time

- Date
- Latitude
- Longitude
- Time Zone

A battery-backed, temperature-compensated, on-board real-time clock supplies the time and date while the other system-defining parameters are stored in non-volatile memory within the microcontroller itself. Upon completion of the final calibration procedures, the clock will keep time to within fifteen seconds per year without attention. The tracking accuracy, depending on structural and electronic feedback characteristics, can be maintained to within 0.02 degrees. (Leonard, Solartrak Software interface manual, 2002)

The 6811 based proprietary controller is still in working condition and are still sold today by Precision Solar Technologies. The array was rotated 180° from its original installation in Rockingham which meant the tilt axis limit switches and reference offsets had to be reconfigured.

Most of the tracking variables setup previously used at Rockingham campus were still valid after the move to South Street with the exception of the following:

- Geographic Location (Longitude and Latitude)
- Reference Offsets
- Limit Positions
- Gear ratio

These values have since been checked and updated where necessary to make the unit operate properly.

The Solar Trak Controller comes with a built in LCD screen which allows viewing of critical variables to controlling the Solar Array. However there are many more variables that need to be initialised when commissioning the array. To do this using the LCD screen would be a long task. The board is also built to interface with proprietary software and an extra USER Board which display the variables to simplify the process of commissioning. These interface methods allow for the backup and restoration of settings.

2.2 Field Interface board

The field interface board was upgraded as part of this project for the following reasons:

- Provide more room for components
- Addition of Interlocking relays
- Neater layout of components for easy debugging
- Limit switch wiring brought back to controller box for easy debugging
- Addition of a GPO for the connection of a configuration laptop
- Protection of dangerous voltage from students
- Future upgrades

The previous field box shown in Figure 8 had little room to add the upgrades to the system and lacked a logical layout. It was decided to move to a larger box to incorporate all of the proposed changes and keep the board simple to debug whilst providing room for future expansion. The use of a wire labelling system also helps to keep the board easy to debug. The completed field interface board is pictured in Figure 9.

ENG454 Students had completed the electrical design for the large array at the start of this project. Testing of the individual field components had been carried out with a few replacement parts being ordered by the students. A finalised copy of the electrical design was produced using TurboCAD to provide an electronic form of the circuit diagram. A few minor changes to the electrical design due to issues with sourcing physical components were made at this time. A field box layout was also produced to help maintain a functional layout of components.

The components have been attached to the backplane using the drill and tap method which eliminates the use of nuts on the backplane and thus components can be removed and added with ease without having to hold the nut behind to tighten a component.

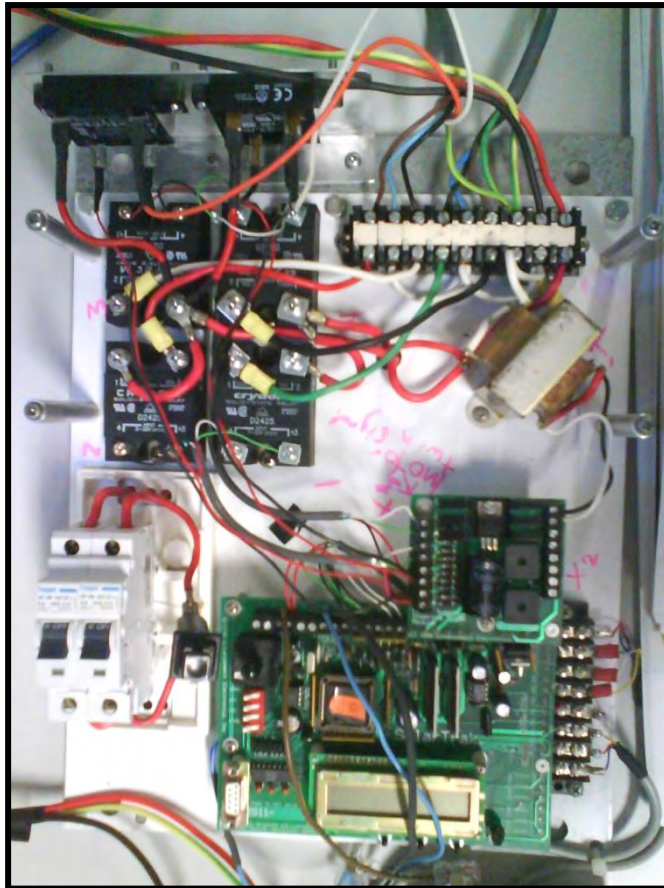


Figure 8 Previous controller board



Figure 9: New Field Interface Board

The board incorporates a clear acrylic sheet that fits over the top of the high voltage components. This protects the user from dangerous voltages while still allowing them to see the layout of the board. By placing a protective cover over the screen students will be allowed to access the Solar Trak controller to check settings without being restricted by the presence of dangerous voltages.

2.3 Interlocking relays

An interlock is designed to prevent conflicting operations occurring by opening particular circuits until conditions are met providing a fail-safe design. Interlocking mechanical relays were added to the field interface board. This was done to prevent the actuation of the single phase AC motors in both directions at the same time. This will prevent a previous fault where a failed solid state relay (SSR) resulted in a burnt out motor.

This fault condition was originally created when a Crydom SSR from the previous installation was found to have failed in the ON (closed) state. If the SSR were to fail the array would have moved to its limit where a limit switch would have prevented damage. However the controller would have kept working trying to actuate the array away from its limit in the other direction the motor would have moved just clear of this limit switch and is then powered in both directions causing damage to the motor.

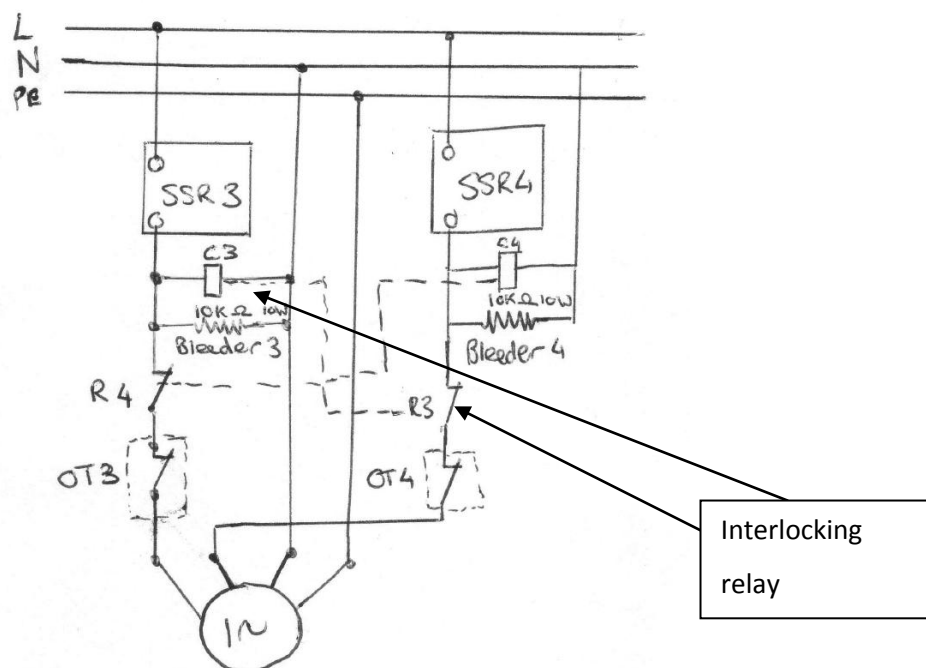


Figure 10: Interlocking Relay Action

The electromechanical relays are wired to operate when an SSR is operating. They are pictured in the top right hand corner of Figure 9. The power to the opposite direction of motion is then broken as it is wired to a normally closed (NC) contact. For example when the clockwise direction SSR is operating the anti-clockwise relay is operating which is preventing power from being supplied to the anti-clockwise direction of motion. The relays come equipped with LED's which are helpful for debugging faulty SSR's.

2.4 Cabling Selection

A design issue that was investigated was the selection of cabling and cabling protection in the system. There are several burn marks on conduit that was previously used in the system as when the trough is not tracking properly there is a risk of the sun being concentrated directly onto the cabling and melting the PVC insulation. The concentrated sunlight can reach temperatures near 500°C at the focal point of the sun which is above the temperature rating of standard PVC insulation. Field wiring suitable for the higher temperatures generated by concentrated sunlight from the mirrors was considered for use in the arrays. The cable is silicone insulated which is temperature rated up to 180°C and costs about 3 times the price of PVC insulated cabling.

However the damage to the cabling was done over 10 years of service and was most likely caused when the array was out of operation and the focal point of the mirrors moved close or onto the cabling. A picture of some of the damage is included in Figure 11.

Part of the design process included placing the cable installed for controlling the array clear of focal points. Due to the small amount of cabling needed for the job the cost for purchasing the cabling was not justified since PVC cabling was available already within the University. A suggested replacement period for the field wiring has been recommended at 5 years due to the harsh summer conditions that the cabling experiences. An inspection period of 2 years has also been recommended to inspect if any damage has been sustained to the cabling or conduit that would make the system unsafe to operate.



Figure 11: Sun Damage to PVC conduit

In the past the controller has had reliability issues with the actuation motor braking mechanism being replaced. During these periods of non operation heat damage to the cabling occurred. Improvements in reliability from adding interlocking relays has reduced the chances of the array faulting which reduces the chance of damage to the new cabling.

2.5 Field Wiring

The field wiring was done with the use of standard PVC coated wiring run inside PVC conduit. ABS plastic field boxes were used to marshal cabling and convert to double insulated PVC wiring that went to field devices. A picture of one of these marshalling boxes is shown in Figure 12.



Figure 12: Field Marshalling

The framework of the array was used to run the conduit and cabling back to the field box which was placed under the tilt mechanism which minimised cable lengths. Conduit was deliberately run on the bottom side of beams to minimise the sun damage to the conduit from both the direct sunlight and reflected sunlight from the panels. Flexible conduit was used in areas which would be subject to movement.

As part of the project a new housing and attachment shaft was manufactured for the roll encoder. The previous setup at Rockingham was inadequate as it was difficult to dismantle and had the potential to slip meaning there could be missed counts. The new housing and mount was manufactured by John Bolton and consisted of a bolt which was drilled to extend the shaft of the encoder through to the tilt beam pivot axle. The new housing has proven successful as the installation ran smoothly. A picture of the encoder is shown in Figure 13.



Figure 13 Roll encoder

The limit switches were reconfigured on the tilt mechanism to prevent the array from tracking further south than necessary. As the array was spun 180° from its installation in Rockingham the existing limit switch setup allowed the array to track to 80° tilt angle southwards. This is unnecessary as the sun will never reach this point. The limit switches were adjusted by using the screw terminals on the front of the device which rotates the lug. A picture of these terminals is included in Figure 14.

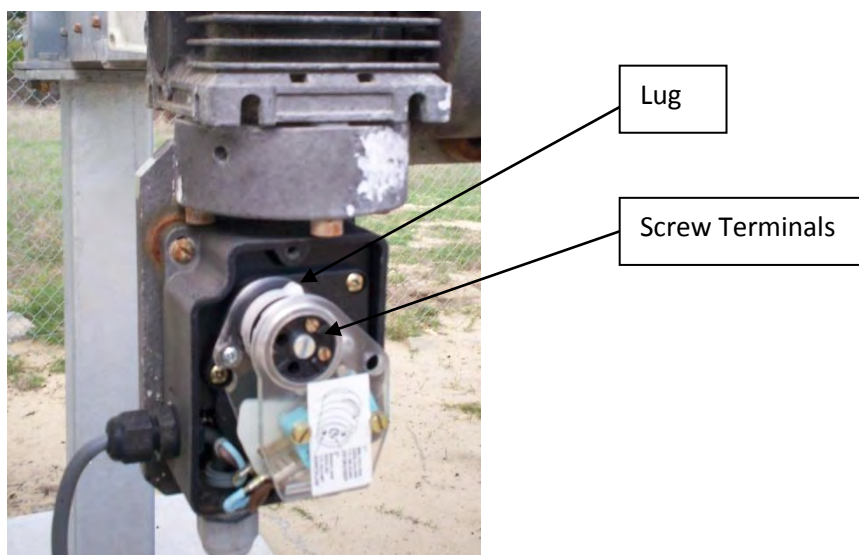


Figure 14 Tilt limit switches

2.6 PC Software

When installed at Rockingham the University had access to a loaned USER Board from the Australian National University (ANU) which they used to update settings on the board. However this board is no longer available. From previous ENG454 group work in semester 1 attempts had been made to use the proprietary DOS based software to communicate with the ST-2011. From communicating with Precision Solar Technologies the software is now fully functional. Copies of the emails exchanged are in Appendix A

The software requires the use of a Windows 98 based computer as ANSI.sys needs to be installed to facilitate communication. The Software is not supported on new systems such as Windows XP currently. A newer version of the software has been supplied by Precision Solar Technologies which has been loaded onto the test laptop shown in Figure 15.



Figure 15: Test Laptop

The program talks directly to the ST-2011 Board via a serial link. To run the program the serial cable must be connected to between the PC and Controller board. The Solar Trak program can then be accessed from the desktop of the Laptop PC by running STN.exe in a folder on the desktop called Rest2011.

The main screen of the controller illustrated in Figure 16 shows the important information about the current status of the controller. It shows live information when connected via a serial link on the following:

- Operational status
- Time and Date
- Sun position
- Actual Array Position
- Wind speed

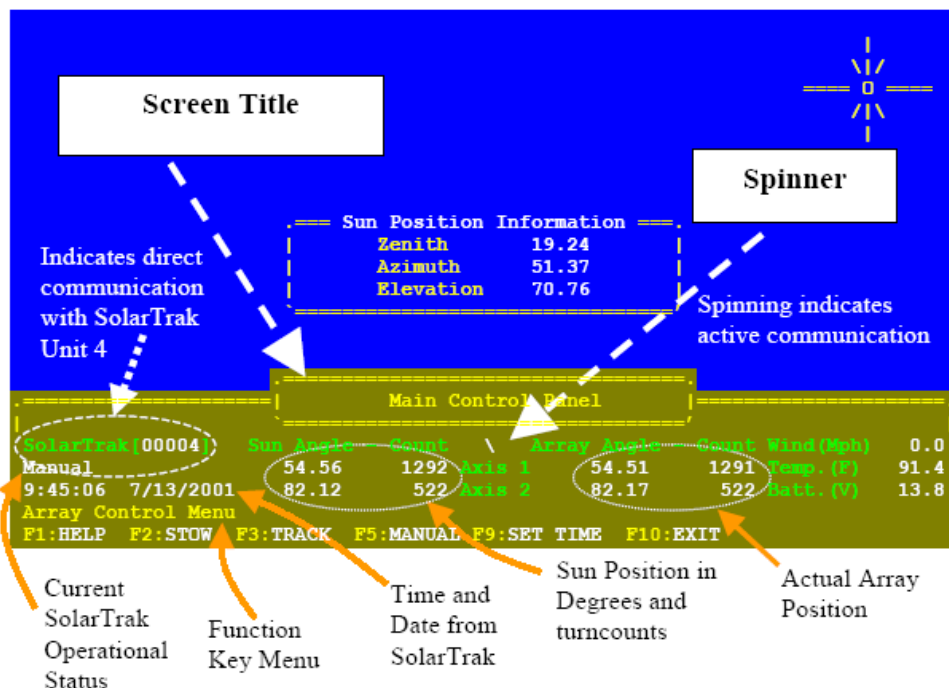


Figure 16: Solar Trak PC interface

To change settings on the controller the configuration screen can be accessed by pressing the forward slash '/' and typing 'CFG'. There are several groups (screens) of adjustable parameters. They can be accessed using the 'PgUp' and 'PgDn' keys. To change a parameter, highlight the offending value using the UP and DOWN arrows then press 'ENTER'. 'F10' will exit this menu and return to the main control panel. 'F10' can also be pressed again to exit the program.

Particular attention must be taken to the position references used in the Solar Trak Manuals. The Solar Trak controller is able to be used worldwide however many references to directions relate to the northern hemisphere. For example:

The North limit is the furthest position that the array can achieve when moving away from the Equator(Leonard, Solartrak Software interface manual, 2002)

However in the southern hemisphere this interpretation is reversed. The above statement should be modified to:

The South limit is the furthest position that the array can achieve when moving away from the Equator.

There are numerous other references in these manuals which confuse interpretations of instructions. Detailed instructions and information on how to use the PC software and setup of the controller are included in Appendix B.

2.7 Testing

Bench Test

The controller board was tested on the bench top with John Bolton wiring a small array of lights and switches pictured in Figure 17 to complete the test. The board passed all tests and performed how it was designed. The most significant change to the design from its installation at Rockingham was the inclusion of interlocking relays to prevent the SSR's from driving the motor in both directions if they fail.



Figure 17: Bench Test Board

The original bench test showed a flaw with the SSR's off state leakage current when no load was connected to the circuit but at the time was dismissed due to the relevance of the problem. It was believed this leakage current would be dissipated through the motors when connected in the field. The condition where a motor hits a limit switch and causes an open circuit was over looked.

Field Testing

Once connected in the field an initial movement test was carried out to make sure that the motors were connected in the correct direction. The controller manual stated that the array should move north when the joystick is pressed UP and south when DOWN. The roll axis should move east when RIGHT and west when left. The system moved correctly in all of these directions.

The next test performed was confirming that the limit switches were connected properly and stopped the array. This was done by holding the limit switches for each direction of

motion and manually moving the array towards them. The system passed this test as the array did not physically move when power was applied to the circuit.

In the next test performed, the array was driven to its limits to make sure that the limit switches were aligned properly and operated. The array stopped at all limit points however this caused the OFF state leakage current of the SSR to flow through the interlocking relay coil. As a result the array was the stuck at this position. Under automatic operation the array would become stuck every morning when it performs a reference check. A solution to this problem was investigated and fixed as discussed in section *2.8 Bleed resistors*.

The next test performed was to verify the reference offsets were correct and the array was able to track the sun. A morning reference check was performed and the offsets were adjusted accordingly. It was found that the roll mechanism was moving in the opposite direction as the array had been spun 180° from its installation. This was accounted for by changing Ax2 (Roll) gear ratio to its negative equivalent. A new reference offset was chosen experimentally to align the array with the sun. A summary of the parameters modified on the microcontroller can be found in Figure 18.

The Tilt (Ax1) + Limit was modified due to mechanical problems with the array. At settings further north the array would become stuck with the tilt axis not having enough starting torque to move the array. This setting was chosen and hard limits adjusted to prevent the array from moving into this region. Until this mechanical issue is fixed there could be problems with tracking accuracy during winter months as the system is prevented from moving to these higher azimuth angles.

Parameter	Old setting	New Setting
Roll Ax2 Gear Ratio	644.5787	-644.5787
Roll Ax2 Ref offset	-375	1610
Tilt Ax1 + Limit	12900	8800

Figure 18: ST-2011 Changed parameters

Monitored Tracking

A test was setup to monitor the array over one day of use to make sure that the tracking system has been properly configured. This test involved monitoring the open circuit voltage of the cells which would indicate that the sunlight is being reflected onto them. The open circuit voltage was logged to a computer by connecting a Protek 506 digital multimeter to the cells terminals. The multimeter was setup in “RS232 mode” and “Keep on mode” To

setup these modes press the menu button until the setting is flashing. Press the enter button to accept these settings. A small serial logging program was made using labview to poll the protek meter every 5 seconds for the DC voltage. The serial interface uses the communication settings outlined in Figure 19. The data was then written into a spreadsheet with the current time. The data is displayed in graph form in Figure 20.

Parameter	Setting
Baud rate	1200
Data bits	7
Parity	None
Stop Bits	2

Figure 19: Protek serial settings(Protek)

As a further check web cameras were used to record the movement of the array and verify the sun was hitting the PV cells. The test was run on the 16/11/2010 with no clouds in the sky and a maximum temperature of 30.3°C. The test was a success with both the open circuit test and web cameras verifying the array was tracking correctly. More details of the test including the video footage from the web cameras can be found in Appendix I.

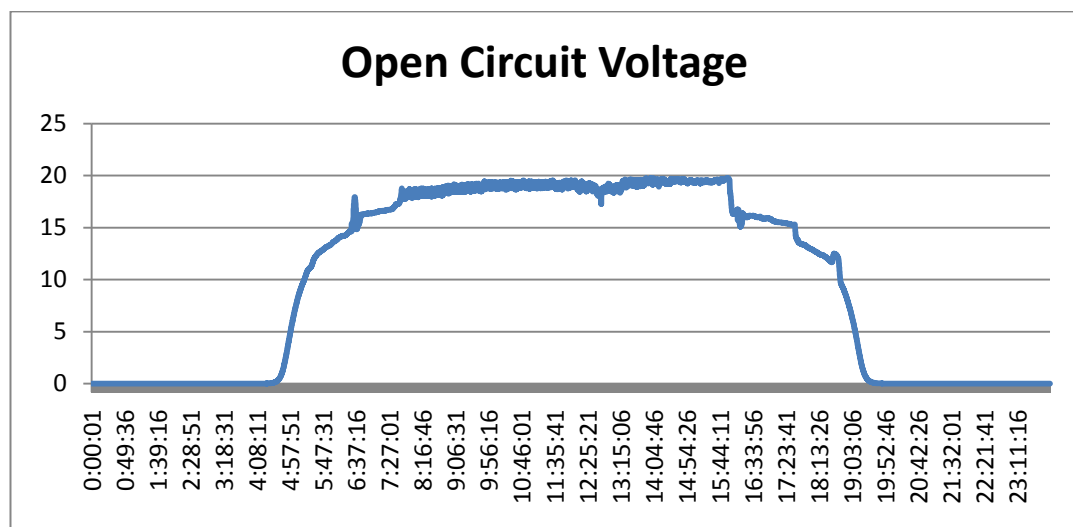


Figure 20: Open Circuit test results

Figure 20 shows that the open circuit voltage of a PV cell that is tracking stays around 19V which indicates that the array is tracking during the hours of 7:45am to 4:00pm on the test date. The video attached in Appendix I shows the focal point of the sun is aligned with the PV cell throughout the day.

2.8 Bleed resistors

When there is no load connected the gate voltage on the SSR will float. This is enough to excite the interlocking relays and could cause confusion when debugging. For instance if the system hit a limit point. A bleed resistor to dissipate the OFF state leakage current has been installed in parallel with the load that will dissipate the OFF state leakage current thus preventing the array being stuck at a limit point. The resistors will redirect the leakage current away from the mechanical relays by providing a lower resistance path to neutral. A circuit diagram for the connection of a bleeder resistor is included in Figure 10.

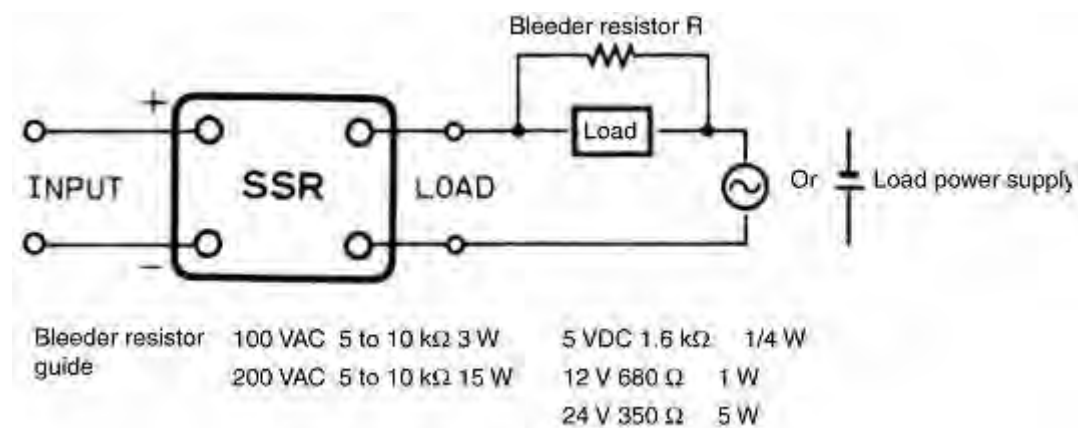


Figure 21: Bleeder resistor circuit diagram

As the bleeder resistor guide says in Figure 21 a resistor should be between 5 to 10k Ω . A resistor has been chosen as the OFF state leakage current is 10mArms. A 10k Ω resistor will dissipate 24mArms which is more than adequate. The chosen resistor is a backplane mountable 10k Ω 10W resistor which is well above the normal power of 5.4W running through it.



Figure 22: Chosen Bleed resistor

The chosen wire wound resistor is a surface mount device similar to Figure 22. This has allowed for easy mounting on the backplane.

3.0 Small Array

The small arrays are two similar arrays each designed to carry 8 receivers. A new control system is being developed which will demonstrate the use of modern Variable Speed Drives (VSDs), lab view and RS485 Technologies to move the two small trough arrays. The small arrays were formed from parts left over from the original 80 panel array installed at Rockingham. A diagram of the layout of the small arrays is shown in Figure 6.

The control system has been designed using lab view and integrates the use of a time based tracking algorithm involving the calculation of solar time using the Julian calendar. The chronological control system calculates the suns angle at a particular time of day and moves the actuators accordingly using RS-485 as the communication medium talking the SEW communication structure.

Work is currently under way to mount servomotors directly to the tilt and roll mechanisms. At the start of this project the tilt SEW servomotors had been mounted to both small arrays by Thistle Contracting and progress had been made with controlling the VSDs by ENG454 Student Groups in semester 1.

Work was needed to be done to design and commission the controller and actuation system so that the system could be controlled automatically. This included:

- Design of the labview controller & solar position algorithm
- Setup of the VSD drive parameters
- Design and manufacturing of a roll direct drive mount
- Commissioning and testing of the controller

3.1 Labview Controller

Students from ENG 454 had started working on parts of the smaller arrays including a lab view program which was able to partially control the VSD's using RS-485 technology. This program has been used as the basis of the controller. The controller allows for an angle input to control the VSD's using the IPOS positioning and sequencing program which moves the motor into the requested position.

The labview program relies on using the SEW proprietary software to set the VSD up to accept input from the RS-485 bus. This issue still needs to be corrected but an investigation into the registers that are being set by the SEW software has been carried out using a serial port sniffing program made with labview. A copy of this program is included in Appendix I.

These registers will remain the same until the SEW software is used to manually control the motor which sets the setpoint source and control signal source to “SBus”. The registers that are modified are shown in Figure 23. Thus this issue is minor as it has been documented. The controller has been developed to handle communication to more than one VSD which is allowed by the RS-485 communication structure.

Par. no.	Parameter	Index		Unit/index			Access	Default	Meaning / value range
		Dec	Hex	Abbr.	Sz.	Cv.			
1.. Setpoints/ramp generators									
10. Setpoint selection									
100	Setpoint source	8461	210D		0	0	N/R/RW	0	0 = BIPOL./FIX.SETPT 1 = UNIPOL/FIX.SETPT 2 = RS-485 3 = FIELDBUS 4 = MOTOR POT 5 = MOT.POT +AI1 6 = FIX SETP+AI1 7 = FIX SETP*AI1 8 = MASTER-SBus. 9 = MASTER-RS-485 10 = SBus
101	Control signal source	8462	210E		0	0	N/R/RW	0	0 = TERMINALS 1 = RS-485 2 = FIELDBUS 3 = SBus

Figure 23: Setpoint sources

Multiple Motors Controlling

The controller has been adapted to control multiple motors. At the moment this is done by using the loop counter to alternate transmissions to the different devices. The labview blocks shown in Figure 24 simply covert the loop count into a binary number and read the least significant bit. This system does not use buffering as the inverter transmission packets stay the same for a long period of time relative to the communication loop and are repeated thus there is little chance of the inverter missing a transmitted packet. Packets received by the PC are sorted by their inverter address and held in shift registers until a new update is received. Essentially all of the controls for the motor and feedbacks were duplicated in Labview. This has resulted in a comprehensive set of dials and displays on the front panel. Further simplification is advised as a lot of the controls and indicators are only useful for testing purposes. A final simplified field version of the program is recommended which has had the debugging parts of the program removed.

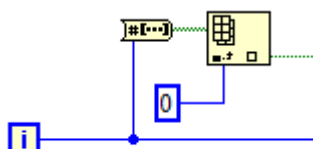


Figure 24: Labview implementation of multiple device communication

Automatic Mode

The user decides if the arrays should be in the following modes via a tab interface in automatic mode. There are 3 options available are:

- Tracking mode: Calculates and tracks the sun
- Manual Stow: Moves to user input stow position
- Cleaning mode: Moves to a predetermined position where the array is easier to wash

When the controller is put into tracking mode a state program takes over the control decisions. The diagram in Figure 25 shows the states available in tracking mode and their purpose.

States have been setup using a dedicated type definition in Labview. This ensures that any additional states added later will be automatically carried onto each control that is in this program. A type def is created by right clicking on the control in the block diagram and selecting 'open type def'. This will open the control in a separate window. Changes can be made to the control here including making it a type def or strict type def. Cases can be modified in this screen by selecting the properties of the control. All changes are saved in a '.ctl' file which can be accessed later.

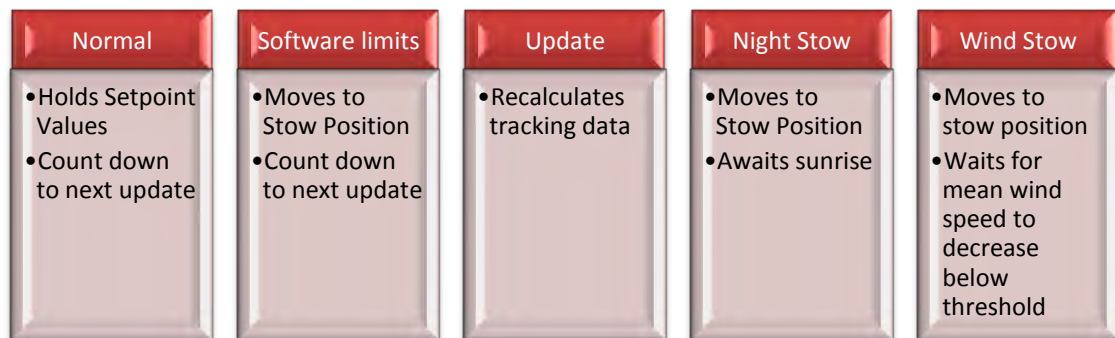


Figure 25: Automatic Mode States

3.2 Solar Positioning Algorithm (SPA)

The Solar Position Algorithm for the small systems have been developed using a technical report by the US National Renewable Energy Laboratory. It uses similar calculations to the large systems but has an increased accuracy. The report outlines detailed calculations for calculating the solar zenith and azimuth angles with uncertainties of $\pm 0.0003^\circ$ (Ibrahim &

Afshin, 2008). The calculations presented in the report used in developing a Labview VI for the calculation of the instantaneous solar zenith and azimuth angles for a given location.

The SPA calculates several values which it uses in its algorithm to calculate the azimuth and zenith angles. These include:

- Julian Calendar Conversions; Julian Day, Julian Ephemeris Day, Julian Century, Julian Ephemeris Century, Julian Millennium
- Heliocentric longitude, latitude and Earth radius vector
- Geocentric longitude and latitude
- Nutation in longitude and latitude
- True obliquity of the ecliptic
- Apparent sun longitude, apparent sidereal time
- Geocentric sun right ascension, geocentric sun declination
- Observer local hour angle
- Topocentric sun right ascension, Topocentric local hour angle

Calculations that require similar inputs have been sunk into Sub VI's to de-clutter the block diagram. A sample Sub VI is shown in Figure 28. An illustration of the flow of calculations is shown in Figure 26.

The SPA is called by the main controller to compute the azimuth and zenith from the current local time as its sole required input to simplify the connections needed in the main controller. All other variables such as longitude and latitude are already defaulted at the current geographic location. This saves clutter on the controller screen as these variables are fixed for the geographic location.

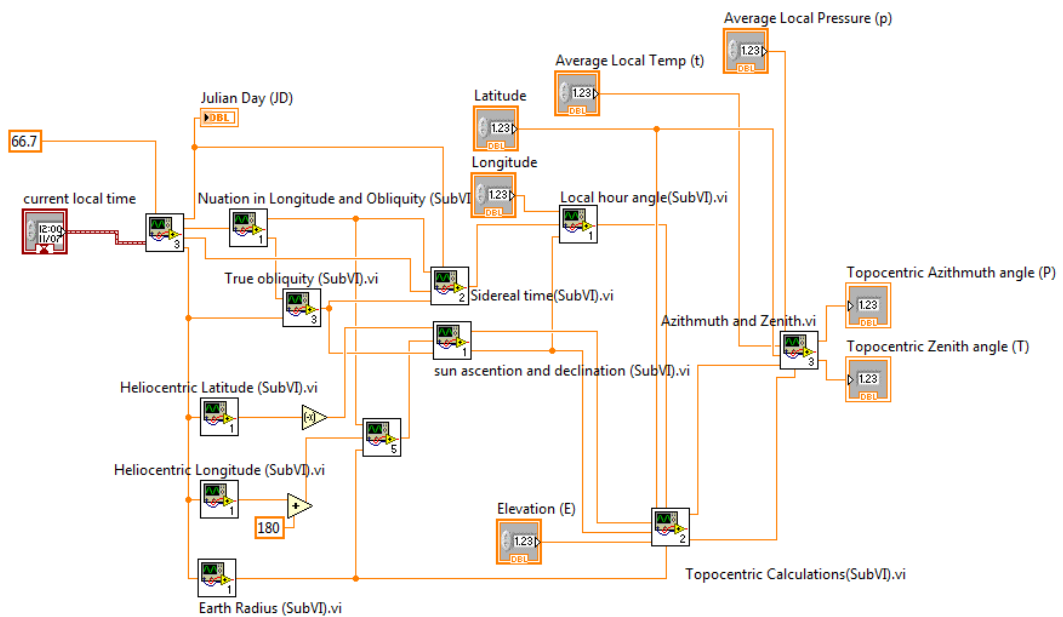


Figure 26: Labview Solar Position Algorithm

Most of the angle calculation involved in the SPA was presented in degrees. As Labview's trigonometric functions can only handle angle measurements in radians, values passed around the program are often converted from degrees to radians and vice versa. The formula and its labview interpretation for conversion of radians to degrees and vice versa is shown in Figure 27. A sample subVI is shown in Figure 28, which illustrates the method used for conversion of angle units throughout the program.

	Degrees to Radians	Radians to Degrees
Formula	$\frac{\pi}{180}$	$\frac{180}{\pi}$
Labview		

Figure 27: Converting Angle Units

The SPA uses 12 subroutines to calculate the necessary variables using formula nodes to perform calculations and CSV data to import the constants needed. The program and its sub routines are then called into the controller VI to give this information with its only input the system time and date from the PC and the geographic location. Each subroutine is based on a section of the National Renewable Energy Laboratory report.

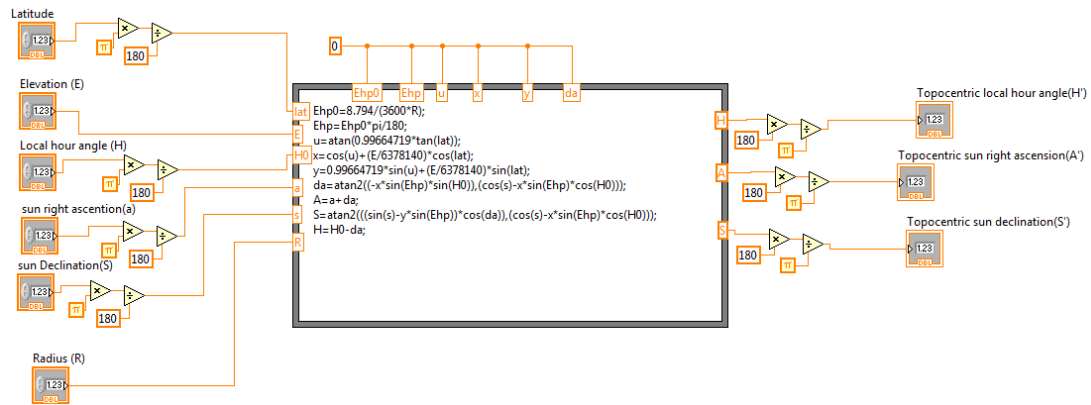


Figure 28: Topocentric Calculations SubVI

The front panel of the SPA is relatively simple. It allows for the setup of the geographic location and input of the local time. The SPA is a single loop program which calculates the zenith and azimuth angles from these inputs when the run button is click or called by another VI. The National Renewable Energy Laboratory technical report also built in atmospheric refraction correction and elevation correction into their Algorithm. These calculations have been passed on in the Labview SPA. However, the data required for these calculations has not been found in relation to the current geographic location.

The SPA is now complete and performs all necessary calculations passing on the zenith and azimuth angles to the controller. The SPA has been tested using the worked example in the back of the report. It calculates these variables for the given parameters. The calculations have been tested using the Java based Planet Applet by Giesen (Giesen, 2007) however further testing to verify their accuracy has not been performed.

3.3 SEW VSD Setup

Before placing in the field some of the SEW Eurodrive VSD's have been trialled in the Industrial Computer Systems labs to help develop the control system. There are numerous settings that must be initialised before the drive is ready to function. Most of these settings can be initialised by running a drive initialisation setup. This wizard is run from the MOVI tools software and asks a number of questions relating to the motor that is connected to the inverter. To access this wizard a serial or USB link to the XT port on the inverter must be used. The drive can then be scanned for using the SEW software.

The SEW tilt motors have proprietary power and communication connectors shown in Figure 29. These connectors were not delivered with the original order. Replacement connectors have been purchased from SEW and Radio spares. These connectors have been

received by the university and are ready for wiring to the motors. A wiring diagram has been included in Figure 30 for the connection of the resolver.

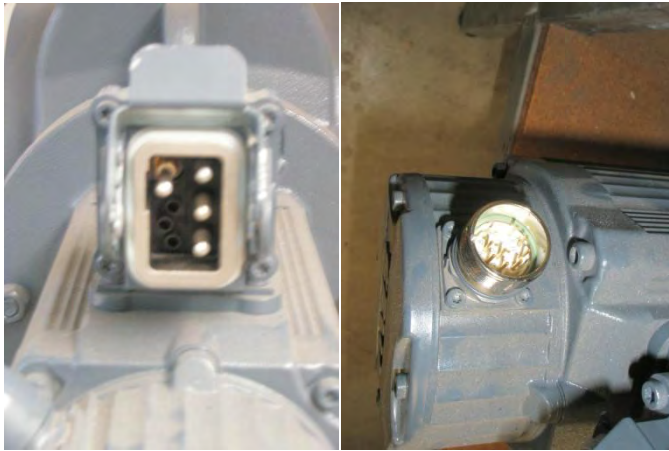


Figure 29: Tilt Power and Communication Connectors

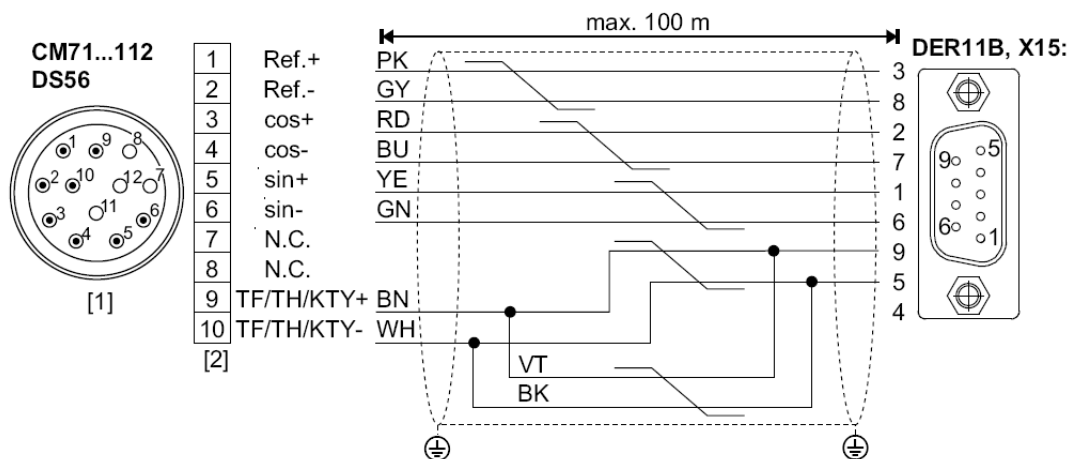


Figure 30: Resolver Connection Diagram (SEW Eurodrive, 2010)

For the drives to operate in IPOS mode the technology enable function of the VSD's must be active. From setting up the test VSD's it has been noticed that this functionality is not enabled by default. The drives were purchased with the assumption that this would be enabled already. So far requests have been made for 2 inverters to be enabled by emailing the technical support at SEW for free. This is done by using the SEW software to generate an email request with the serial number. A TAN number is sent in response that will enable the technology function. Once the drive has been enabled there is no need to re-enable the device for technology function.

The VSD's have a choice of reference modes which can change the way the IPOS counter is referenced. One of these modes uses the limit switches as a reference point. In this mode

whenever the power is reset to the inverter the array must be put back into reference mode where it will search for the limit switch and reset its counter back to zero. Two low voltage limit switches connected to the VSD's limit switch inputs will be needed for each axis which will be used to reference the systems as well as preventing damage. The advantage of this method is there is no need for high voltage three phase limit switches needed to directly break the motor power as they are all run off the internal dc power supply from the VSD and interact directly with the control logic. Currently there has been no limit switches purchased for the small systems.

A bug has been identified which will not allow reverse movement when the VSD is placed in Jog mode and an IPOS reference has been defined. This bug results in the motors only turning in the same direction using the Jog mode when the forward and reverse modes are engaged. A solution for this problem has not been defined yet but other means can be used to move the motors in the required direction such as using manual move mode.

3.4 RS-485 Communication

The SEW Eurodrive VSD's communicate using an RS-485 2 wire bus. RS-485 is a form of serial communication that is based on the popular RS-232 standard. RS-485 expands on RS-232 as it allows for a multi-point network which can handle up to 32 devices on a single 2-wire bus. RS-485 also expands on RS-232 as it can handle up to 1200m of cable on a bus. This makes RS-485 a versatile solution for industrial application where devices must communicate over long lengths.

The RS-485 interface is connected to terminals X13:10/11 on the inverter. The digital ground pin X13:9 on the inverters also needs to be connected together as well as to the shield. A diagram of the connection of the RS-485 bus is shown in Figure 31. The inverters are fitted with dynamic terminating resistors meaning that there is no need to connect a terminating resistor at the end of the bus in the field. However the PC end of the bus must be terminated with a 120 Ω resistor. The termination resistor connects across the bus lines. Without termination resistors on the bus communications can be reflected back onto the bus and corrupt data.

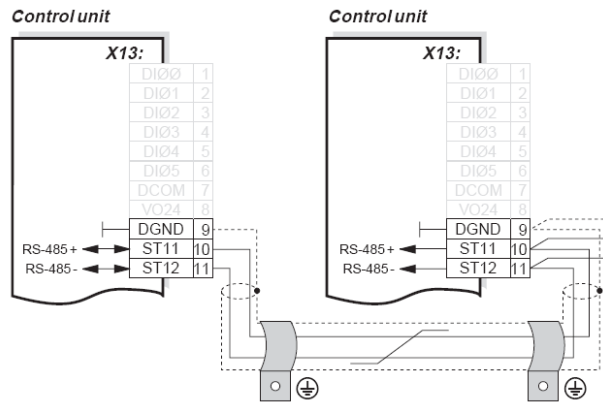


Figure 31: RS-485 Connection(SEW Eurodrive, 2001)

The RS-485 standard dictates all of the hardware limitations however the data protocol that is used on the bus is up to the user. In the case of the SEW VSD's the communication protocol used has been derived by the manufacturer. Detailed information on this protocol is outlined in the MOVIDRIVE serial communication manual. The basic exchanged packet needs have the following setup shown in Figure 32.

RS-485 interface

Standard	RS-485
Baud rate	9.6 kbaud
Start bits	1 start bit
Stop bits	1 stop bit
Data bits	8 data bits
Parity	1 parity bit, supplementing to even parity
Line length	200 m between two stations
Number of stations	1 master and max. 31 slaves

Figure 32: RS-485 interface structure (SEW Eurodrive, 2001)

At present there is a National Instruments RS-485 card installed on the Murdoch University Computer PS-2033-01, which has been used for testing. It is not confirmed if this card will be available for use in the installed system. Alfatron RS-485 converters which are used for teaching were used to trial communications between the controller and VSD's. However as Alan Punch experienced in his thesis establishing communication with VSD's through the use of the Alfatron converters proved unsuccessful (Punch, 2009).

3.5 Control Structure

The labview controllers will make all of the control decisions for the small arrays. The plan was to operate 2 RS-485 links and 2 almost identical labview controllers. This will allow a specific array to be isolated without affecting the communications to other, the control structure is illustrated in Figure 33.

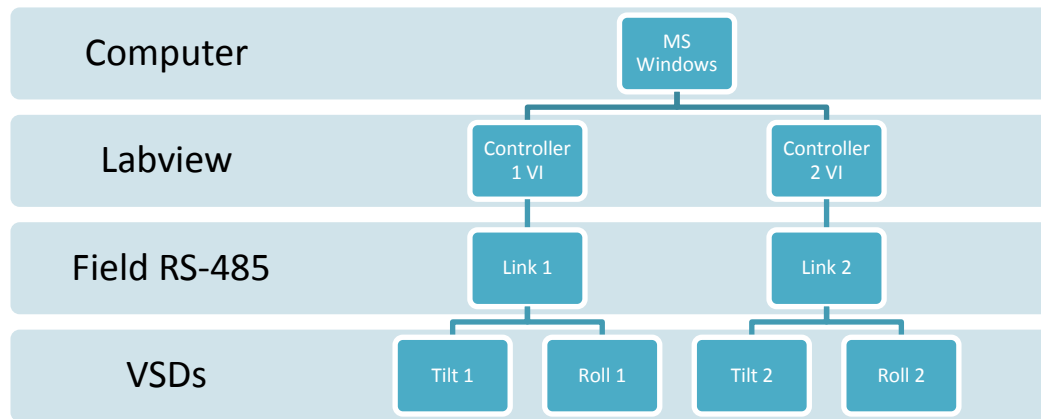


Figure 33: Control Structure

The computer will probably be mounted on site exposed to higher temperatures than normal. For this reason it is recommended that a computer suitable for industrial use be installed as normal computers are not built to withstand these temperatures. However further investigation is needed into the field design as there might be other options available such as added shade to the field box. However given that the computer will be running at low load as the calculations involved in tracking the sun are not a burden to today's modern computers and they are calculated at a low frequency (1min cycles) there is little justification for the purchase of an industrial computer. In the interim an older system could be trialled with the inclusion of temperature monitoring of the motherboard to verify the need for a more suitable system.

3.6 East West Roll Motor Mount

The original intention for the roll motor mount was to use the designs provided by Marko Kretschmer in his thesis report. Kretschmer offered 2 potential designs detailed below:

A **linear actuated** system similar to the existing system on the Large array. The benefit of this system was it was it was relatively easy to mount a linear actuator to the arrays without any modification required to the existing mechanisms. However VSD had already been purchased by the University and linear actuation limited the movement of the

system.

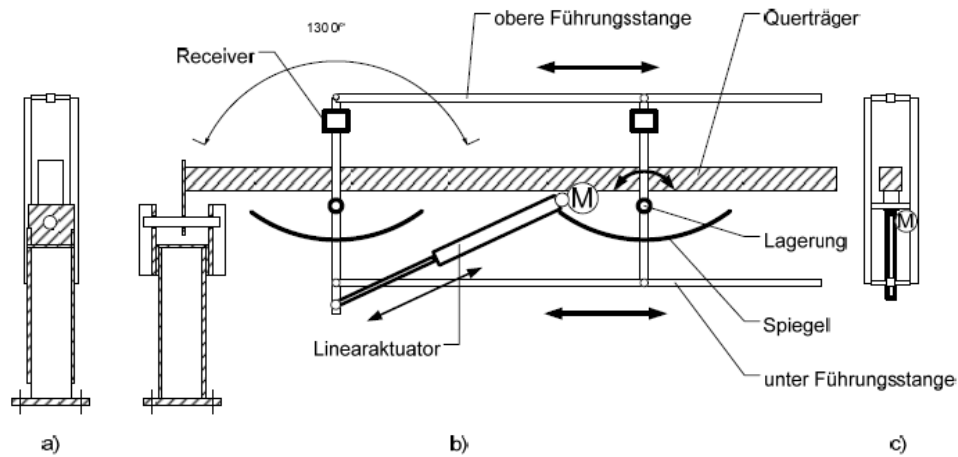


Figure 34: Linear actuator concept (Kretschmer, 2009)

A **Chain Drive** with the VSD mounted onto the tilt beam was also proposed by Kretschmer. This system was relatively simple in terms of the parts it required. However upon further investigation into using his chain drive mechanism it was decided that the sag in a chain drive would provide inaccuracies in control which could be improved upon. The roll framework also required some modifications to be able to install the chain mechanism.

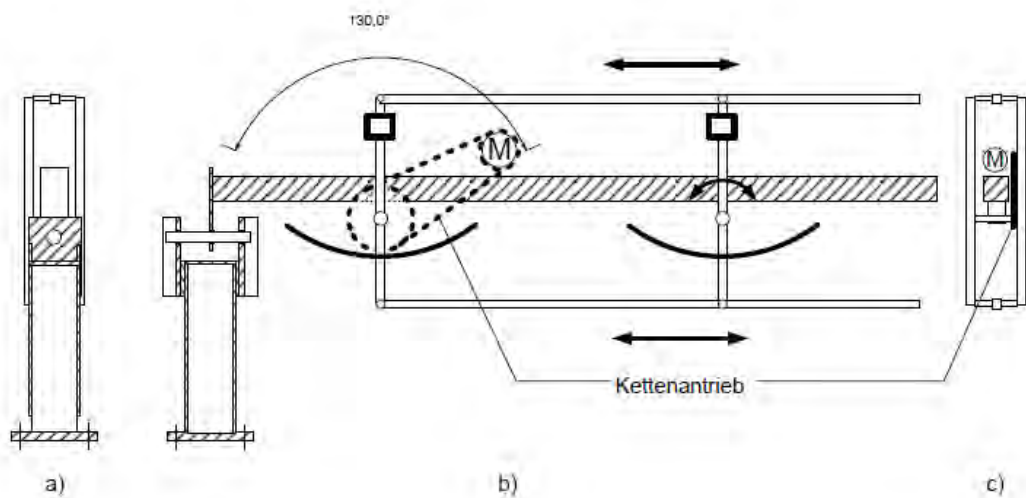


Figure 35 Chain drive concept (Kretschmer, 2009)

After consultation with Graeme Cole and John Bolton it was decided that a direct drive mounting would be the best option for control and also not too difficult to implement. The current design will mount the VSD upside down on the tilt beam and connect the motor in

place of one of the existing pivot points of the system. The direct drive diagram is shown in Figure 36. This will require the modification of many parts on the system including:

- Extending the pivot points of system down to align them with the shaft of the motor.
- Manufacturing a shaft to fit the servomotor gearbox
- Mounting the shaft to the roll framework
- Installing the servomotor
- Installing the Roll framework
- Move oil breathers

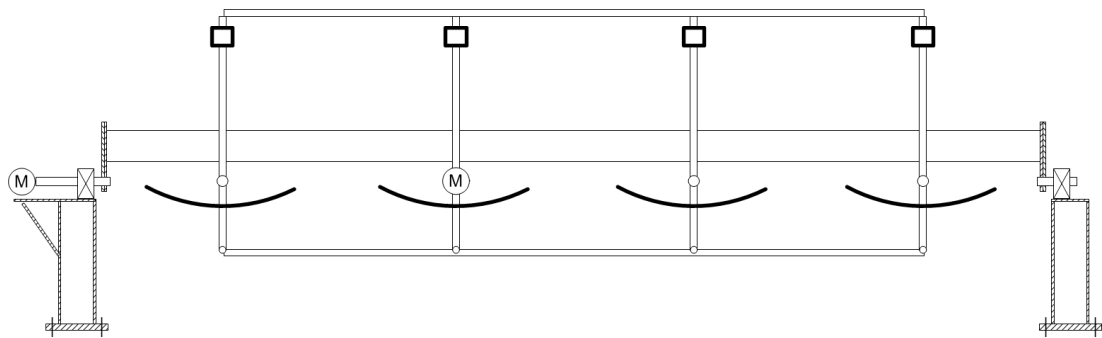


Figure 36: Direct drive concept

It is possible to mount the gear units upside down as shown in Figure 37 however the oil filler, breather and drain plugs must be reconfigured in each mounting position according to the diagram. Mounting position 3 has been agreed upon. This means the oil breather must be moved to the base of the gear unit.

Currently the design for the roll motor mount has been agreed upon but due to the time constraints of John Boulton the motor mount has not been completed to schedule. The manufacturing of the roll motor mount will be delayed until the completion of the new engineering building.

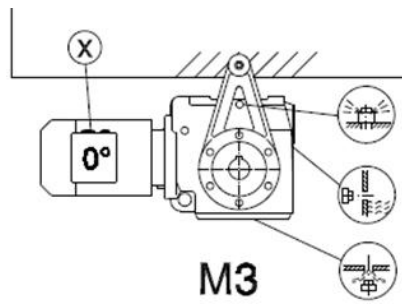


Figure 37: SEW Gear Unit Mounting Positions (SEW Eurodrive, 2010)

Measurements were made using the existing Large array to make sure that the position of the motors in small array will not restrict the movement of the array. This was done by driving the array to its limits and measuring the minimum distances. Details of these tests are provided in Appendix C. It was found that the large systems current setup would not restrict the movement of the small systems when a VSD is installed on the bottom side of the tilt beam.

4.0 Conclusion

Concentrated photovoltaic technology has been more efficient per square meter of panel as the sun is concentrated at 20-30 suns of intensity. Although the system size limits them to use predominately in rural areas they still have an advantage over conventional solar based on cost. Developments in this technology have brought about simple controllers such as the chorological controller that uses simple input variables to calculate and track the sun throughout the day.

The re-commissioning of this technology has advanced my knowledge of CPV technology as well as broadening my practical skills from the implementation and testing of the arrays. The project gave me a greater understanding of project management in dealing with University staff and external companies in the pursuit of completion of the project.

The Large array is now tracking the sun successfully throughout the day. It is now ready to be handed over to the renewable energy department for the installation of inverters and array cabling. This will be the next step on its way to being fully recommissioned and generating on the SWIS again. Some small jobs are still to be completed and are scheduled with John Boulton.

Progress has been made on the small array forwarding its progression towards completion. The design phase is well on its way with decisions made on many major design issues and development nearly finished on the controller. Due to the time constraints of the technical staff at the University the manufacturing will be delayed until the completion of the new engineering building. Documentation of the work undertaken will help any future projects move on and complete the small arrays for use as a teaching resource.

5.0 Future Direction

5.1 Large Array

The solar array tracking system is now in a functioning state with the controller able to operate under automatic tracking. However, there still needs to be work done on the controller to make the installation permanent, to ensure safe operation and to improve control accuracy. The following items are recommended for implementation in the future:

Permanent Power Supply

Currently the array has a temporary power supply from an extension cord connected to a power point in the Rise Test area. Cables have been laid from a Sub-main power box in the Test area but have not been commissioned yet. A second field box has been installed behind the controller box to facilitate the distribution of power for other uses such as a 3 phase power outlet. Due to the time restrictions of John Bolton this part is not yet complete.

Emergency Stop Button

Wiring for an emergency isolation switch (EMS) was put into the field interface board. This switch when pressed would isolate the motor drive circuits preventing an accident, while keeping power supplied to the controller in an emergency. Further emergency stop switches could be added later. The wiring has been bridged to allow for testing and commissioning but an EMS should be installed before the array goes into full operation.

Internal Clock

The ST-2011 board keeps its own time using an internal clock crystal. A correction factor is built into the controller to correct any time keeping mismatches. Currently the clock is mismatching by a few seconds per week which over time amounts to a big time difference if left unattended. Experimentation with a different clock correction factor could prove useful in improving the accuracy of timekeeping.

Coast parameters

The momentum of the system is a source for error when tracking the sun, the movement between the time that the controller stops and the array physically stops moving is called the inertia of the system. The inertia of the system can cause the system to overshoot the target position. Coast parameters are available in the controller to optimise tracking which

have not yet been investigated. These parameters could provide improvements in the control of the system.

PV array connection

Currently the PV modules are disconnected and there is no wiring in place for the generation of power from the array. A generation system has been designed by Reginald Edwards in his Thesis but is still in the tender phase. It is vital for the PV modules to be connected the electricity grid (South Western Interconnected System) so the control system has a purpose and can start generating power.

Maintenance Schedule

A maintenance schedule needs to be derived to ensure that this asset is inspected and maintained at the proper intervals. This is important as it helps protect the life expectancy of components by ensuring that small faults do not become catastrophic. It also ensures the system is operating within safety limits.

Realignment of cells

Not all of the PV cells are aligned with each other on the array. This results in some of the cells receiving focussed light and others with no light at all. Now that the array is tracking the process of alignment is made much easier. Currently approximately 25% of the cells need to be realigned.

5.2 Small Arrays

The small arrays remain unfinished at the end of this project. Future projects would benefit from considering the following list for implementation in the future:

Roll motor mount

A design for the roll motor mount has been decided. Manufacturing and installation of this item needs to be completed. John Boulton has been involved intimately in this process. Once the motor mount is complete the roll framework can be attached.

Labview Controller

The labview controller is still in the development stage however the main pieces to the program are completed. It now needs to be debugged and tested fully. The user interface for the controller has a lot of information that is most likely not needed after testing is

completed. A redesign of the front panel would help streamline the user interface. Error reporting functions and further tool tips will also help the user interact with the controller.

Referenced mode reverse

As discussed in 3.3 *SEW VSD Setup* once in referenced mode the VSD's cannot be reversed using Jog Mode. An investigation into a solution for this problem may simplify the programming of the controller.

Renewable Energy Medium

The renewable energy medium has not yet been decided for the small arrays. Possibilities include flat solar panels, which suffer from shading issues, replacement troughs, or solar thermal systems. An investigation into the possibilities for energy mediums needs to take place with consultation from university staff members.

Maintenance Schedule

A maintenance schedule needs to be derived to ensure that this asset is inspected and maintained at the proper intervals. This is important as it helps protect the life expectancy of components by ensuring that small faults do not become catastrophic. It also ensures the system is operating within safety limits.

Field Design

The field design is not complete for the small arrays yet. For the small arrays to be placed in the field a number of items need to be planned and implemented. This includes:

- Limit switch selection
- Field cabinet selection
- Sourcing a Field PC
- Wiring Diagrams
- Field box design

The difference between the large array and small arrays is that the VSD's will handle the limit switches at low DC Voltage levels. This creates a number of possibilities with switch selection as the rated voltages do not need to be as high. The placement of the roll limit switches can be the same as the large array however, as the tilt mechanism has been

completely redesigned with a direct drive shaft there must be a new method of detecting limits.

A field cabinet must be purchased that will protect the VSD's and computer from the weather. It must also provide enough room for easy debugging by laying components out in a neat fashion. The cabinet might also require some form of cooling as there will be a computer system housed inside it.

A computer capable of been placed in harsh conditions is recommended for this application. As the computer will be inside a cabinet that is exposed to direct sunlight the operating temperature is a concern. It could be possible to use a standard computer system as the computer does not have to operate under heavy use however further investigation is needed. A temperature monitoring system could be used to assess the suitability of a standard computer system.

A wiring diagram and field box layout diagram needs to be completed for the small system. These diagrams will aid technicians when mounting and wiring the field box. It will also serve as a reference to the as-built system for anyone to consult.

Anemometer

An anemometer is needed for the small arrays to detect and stow the arrays when there are severe wind conditions above the design specifications of the arrays. Currently the tracking program has the wind stow mode built into it however an anemometer needs to be purchased.

It is also undecided how the anemometer will decide if the arrays should be stowed. Possibilities include:

- Instantaneous wind reading above threshold (Gusts)
- Average wind reading (Time period?)

However both conditions have pros and cons. Taking an instantaneous reading would result in the arrays being stowed often but using an average could result in the instantaneous reading being well above the threshold range. From looking through the documentation for the previously installed array in Rockingham system the ST-2011 controller is set to stow the Large array when the wind speed is over 70km/h for 2 seconds. It is suggested that the same wind speed reading be used on all arrays for simplicity.

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